CF2: WIMP Dark Matter Indirect Detection (Parallel Session)

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CPM 2012 FNAL Oct 12, 2012

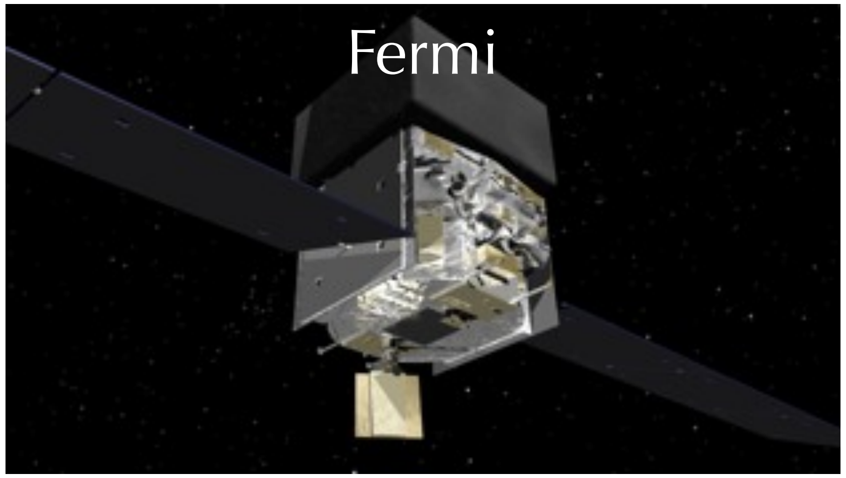
Outline

- Indirect Detection - Where it fits, what it is.
- Agency advice: Build science plan for each area for next 10 to 20 years, help with the decision tree, explain balance of complementary methods, guidance on making decisions of which techniques are needed for dark matter, theoretical effort to make the case, how could results in one area affect where we go in other areas - write DM science plan.
- Open forum discussion of the charge:
  - Science Drivers
  - What experiments should be covered?
  - What metrics should be used to evaluate the potential of Indirect Detection for DM science?
  - Identify overlaps with other subgroups.
  - Participate in discussion with CF1 and Instrumentation groups
- Please contribute comments, or a SINGLE overhead, I will try to record these comments and provide feedback to the Cosmic Frontier group.

Complementarity

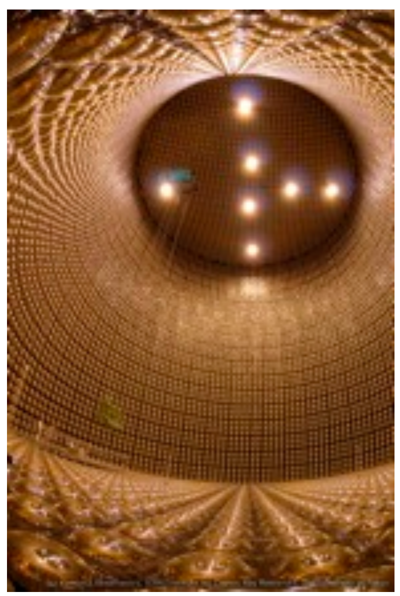
Dark Matter

Experimentes

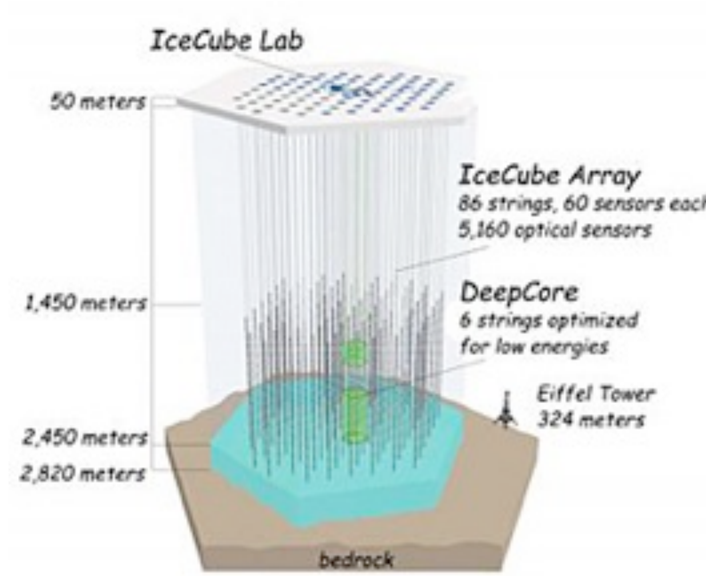


γ

Super-K

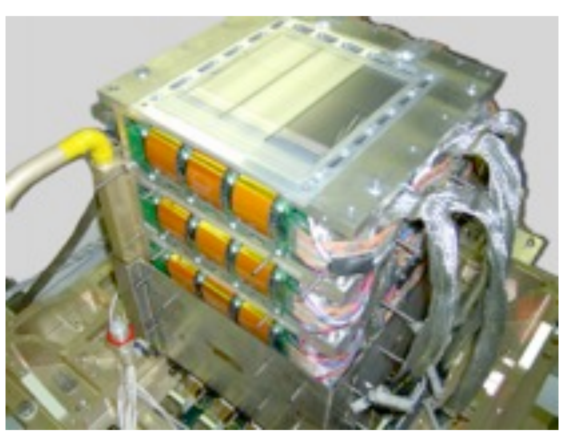


ν



ICECUBE

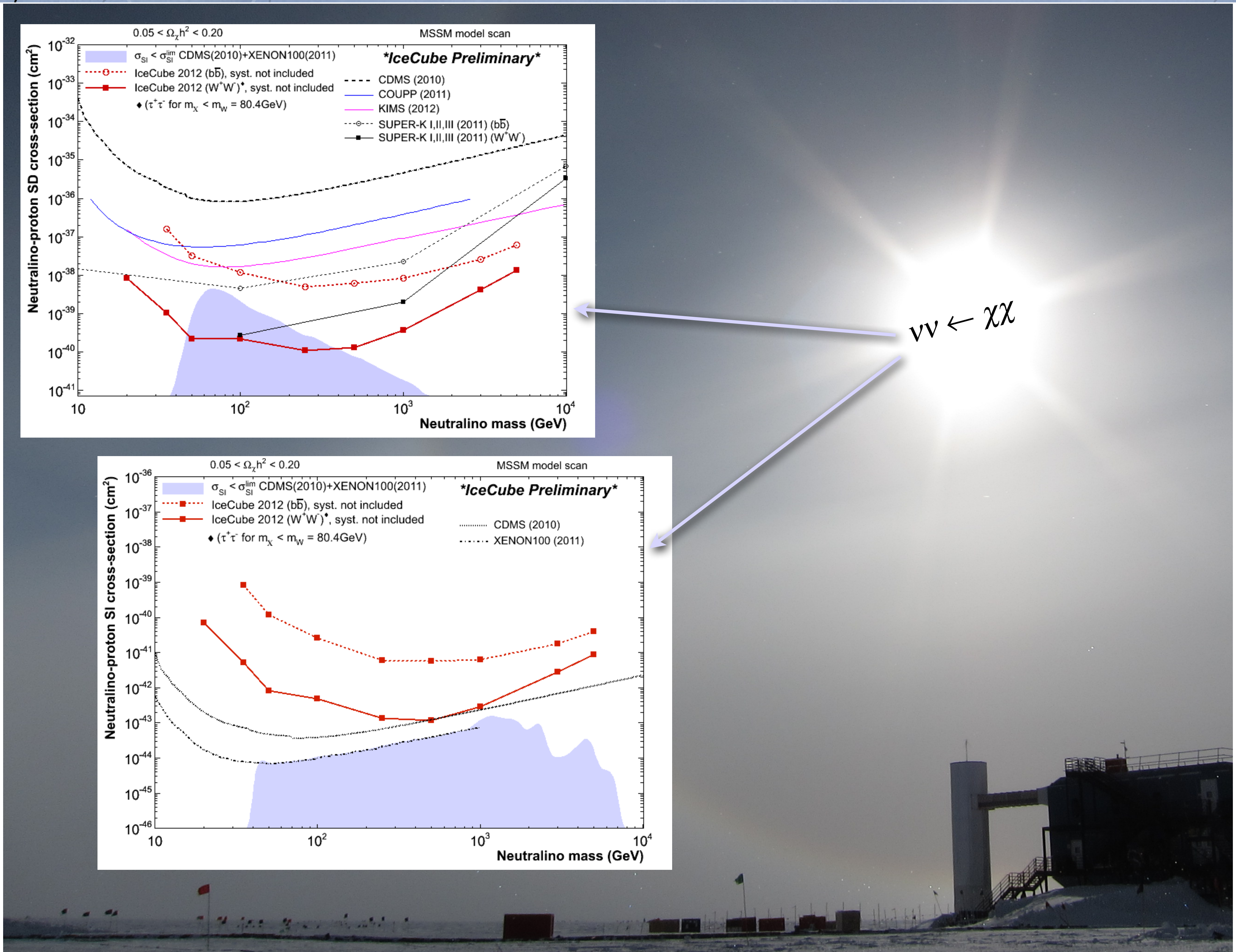
PAMELA



$e^-, e^+, p, \bar{p}$

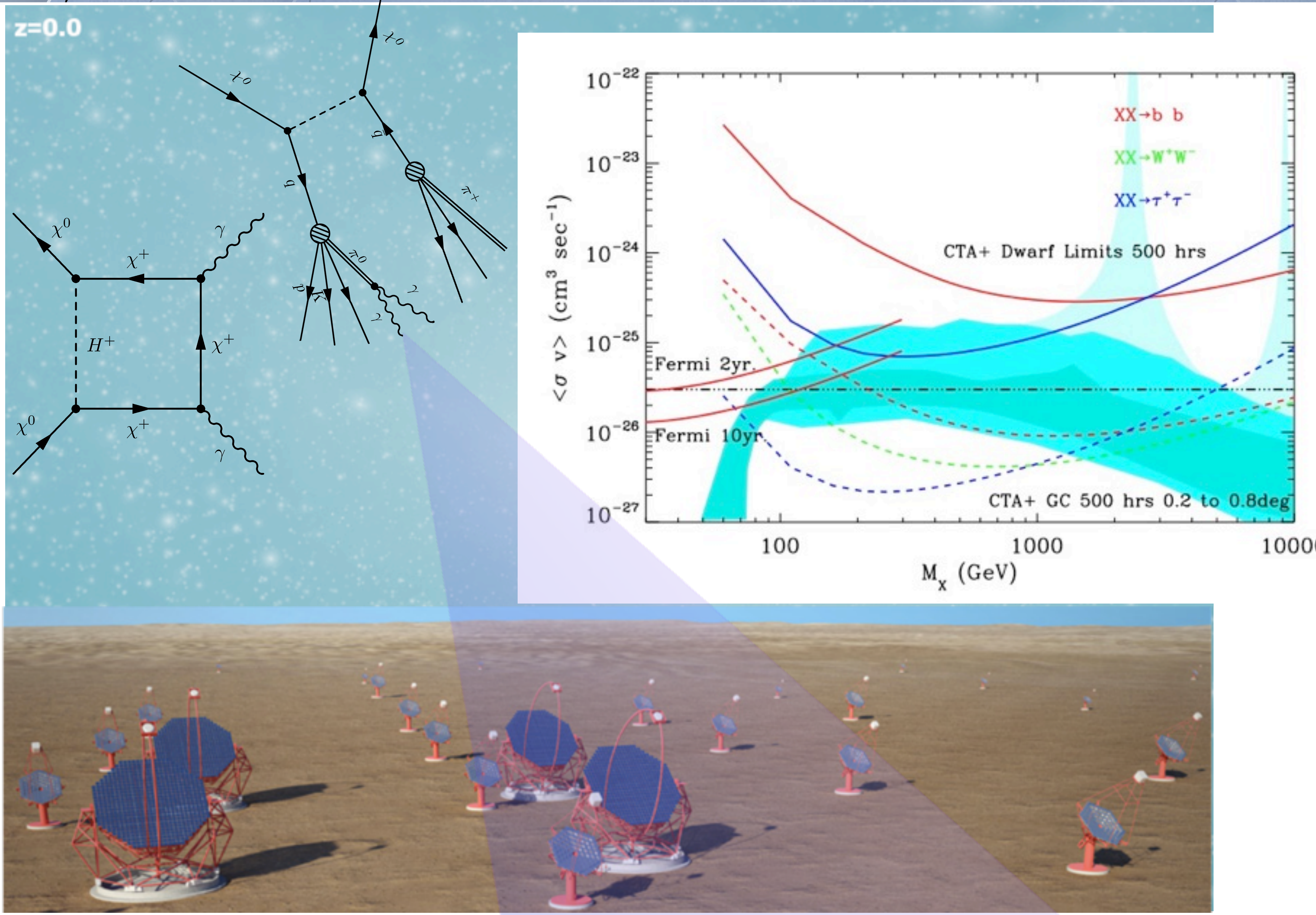
AMS

Neutrinos



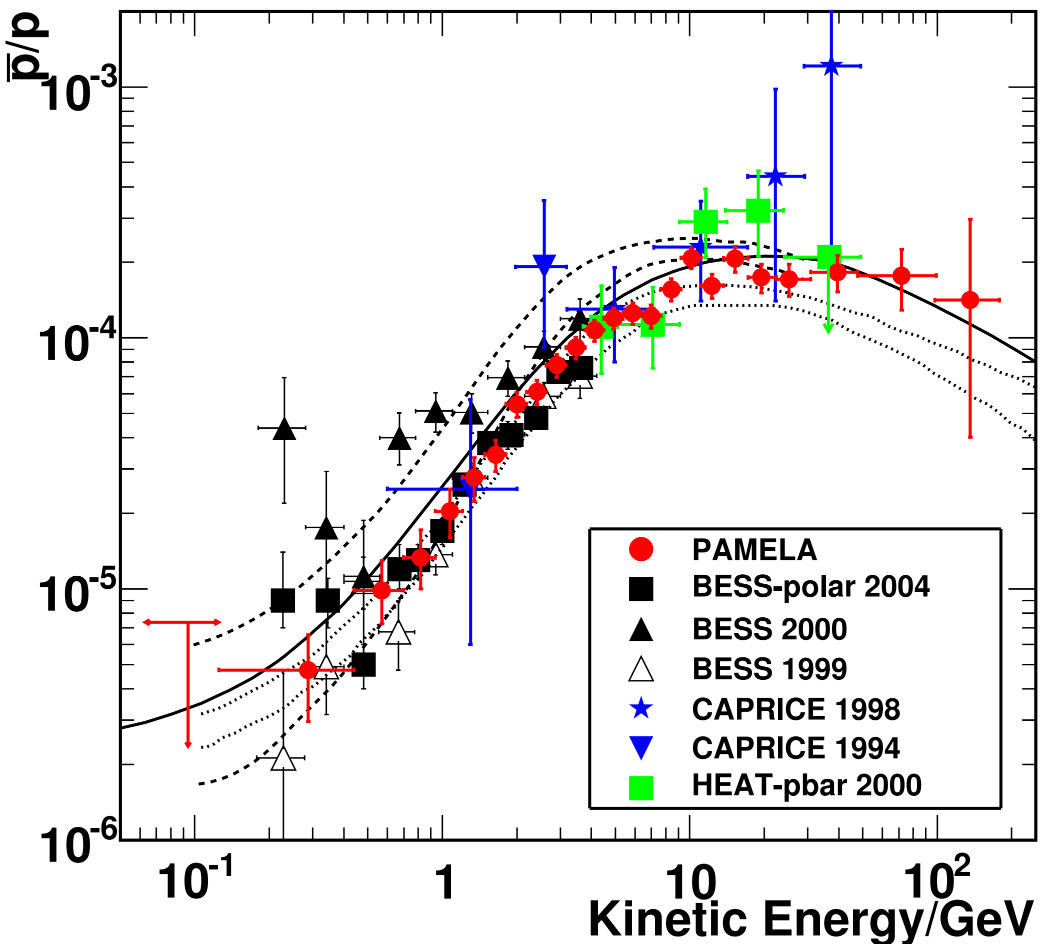
0.05 < Ω_χh² < 0.20
MSSM model scan
IceCube Preliminary
CDMS(2010)+XENON100(2011)
IceCube 2012 (bb̄), syst. not included
IceCube 2012 (W⁺W⁻)♦, syst. not included
♦ (τ⁺τ⁻ for m_χ < m_W = 80.4GeV)
CDMS (2010)
COUPP (2011)
KIMS (2012)
SUPER-K I,II,III (2011) (bb̄)
SUPER-K I,II,III (2011) (W⁺W⁻)
Neutralino-proton SD cross-section (cm²)
Neutralino mass (GeV)
XENON100 (2011)
Neutralino-proton SI cross-section (cm²)
νν ← χχ

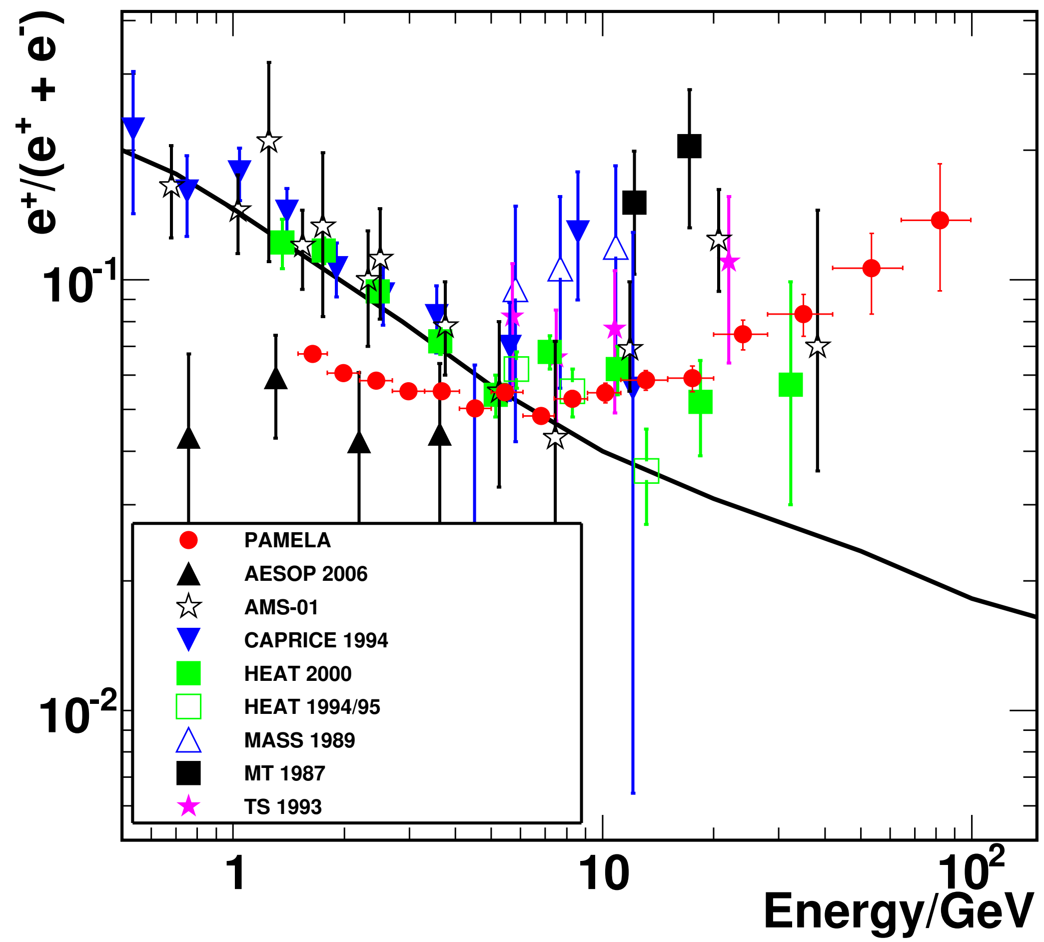
Gamma Rays



z=0.0
XX→b b
XX→W⁺W⁻
XX→τ⁺τ⁻
CTA+ Dwarf Limits 500 hrs
Fermi 2yr.
Fermi 10yr.
CTA+ GC 500 hrs 0.2 to 0.8deg
<σ v> (cm³ sec⁻¹)
M_x (GeV)
10⁻²²
10⁻²³
10⁻²⁴
10⁻²⁵
10⁻²⁶
10⁻²⁷
100
1000
10000

Positrons and Antiprotons



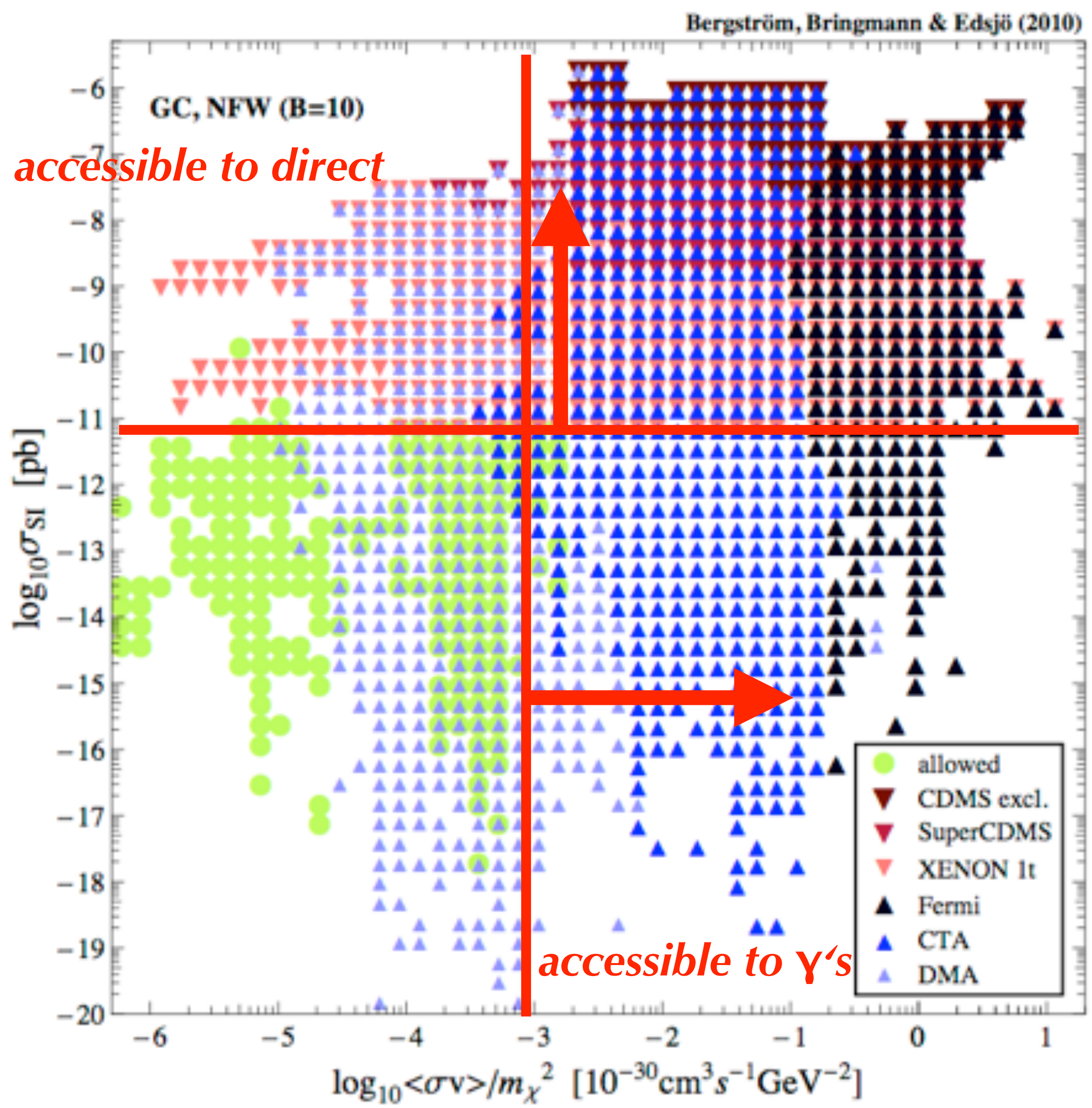


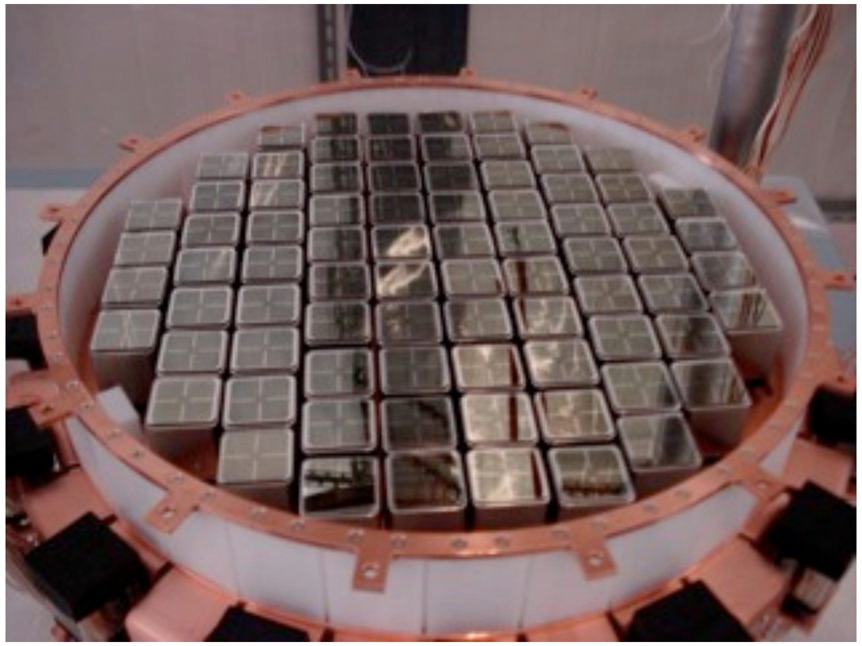
- Positron excess but no antiprotons motivated leptophillic models to boost electron production, while suppressing hadronic channels.

Direct and Indirect Detection

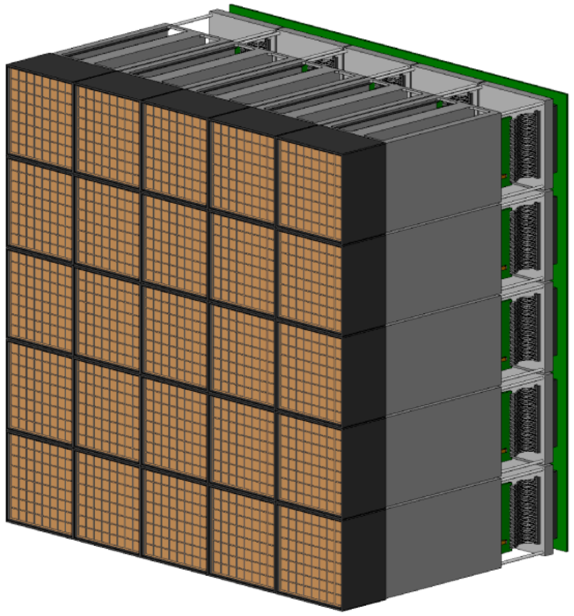
Dark Matter can be directly detected through nuclear recoil in “direct detection” experiments, missing energy or momentum in accelerators, or through detection of products of annihilation in astrophysical halos

[hep-ph] arXiv:1011.4514 L. Bergstrom et al.





Xenon100



Proposed CTA SC camera module

Cosmic Frontier Working Group

Charge for the WIMP Dark Matter Indirect Detection subgroup

(James Buckley, Doug Cowen, Stefano Profumo)

(1) ***Summarize the Status and Current Issues:*** Apply to all indirect searches for dark matter an agreed-upon set of benchmark annihilation final states, dark matter density profiles, substructure setups and velocity distributions, and parameter space to use for side-by-side comparisons. Articulate what would be lost if one or more of the various approaches were not pursued over the next decade. Summarize the potential sensitivity and anticipated uncertainties for each technique or project.

(2) ***Complementarity:*** Assess the complementarity of different current indirect detection techniques, and of indirect detection with direct and collider searches. Coordinate with CF1 and CF3. Compare in particular the prospects for constraining the SD cross section with indirect detection (e.g. of solar WIMPs) vs. direct detection.

(3) ***Future Experiments:*** Describe the attributes of future experiments for DM detection, addressing the relevance of sensitivity to the GC, the importance of angular resolution, FoV, and threshold energy. Compare to the anticipated results from existing facilities in the same timeframe. Consider new and possible future experiments such as AMS (cosmic ray electrons and positrons), CTA (gamma rays), IceCube/PINGU (neutrinos) and other future experiments. Assuming detection of dark matter, evaluate how well its properties can be measured by each such experiment.

(4) ***Theoretical HEP Issues:*** Survey theoretical models for WIMP dark matter from the standpoint of indirect signals (e.g. assume masses, spin, some effective interaction...). Evaluate the challenges in comparing indirect detection with direct detection, colliders, and dark matter production in the early universe. Discuss the role of (non-SUSY) WIMP models, describe how SUSY space has been (and will be) constrained by LHC results, and compare leading benchmark SUSY WIMP models to one another. Extend the discussion to include axion(-like) particle models and other dark matter models and compare these to models for WIMP dark matter.

(5) ***Theoretical Astrophysics Issues***: Describe the current understanding of halo profiles, clumpiness and velocity distribution and evaluate how their uncertainties impact dark matter searches. Describe the current understanding of the impact of diffuse and point sources as background to searches for gamma-ray signatures of dark matter.

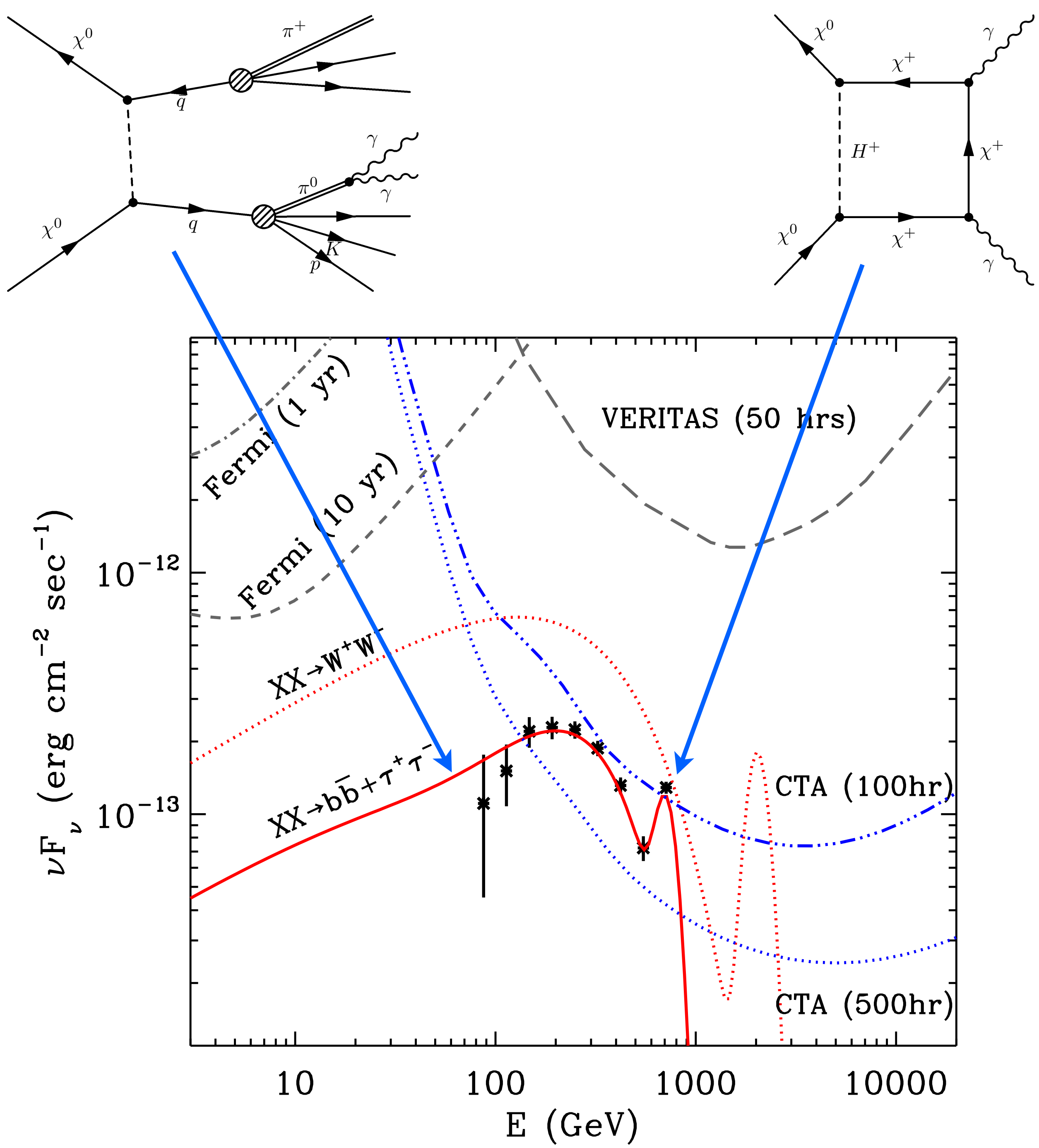
(6) ***Future Detection Technology***: Describe realistically possible advances in detection technology that would have an immediate and significant impact on any of the existing techniques of indirect dark matter detection. Highlight possible “game-changing” advances and describe how they would transform the field.

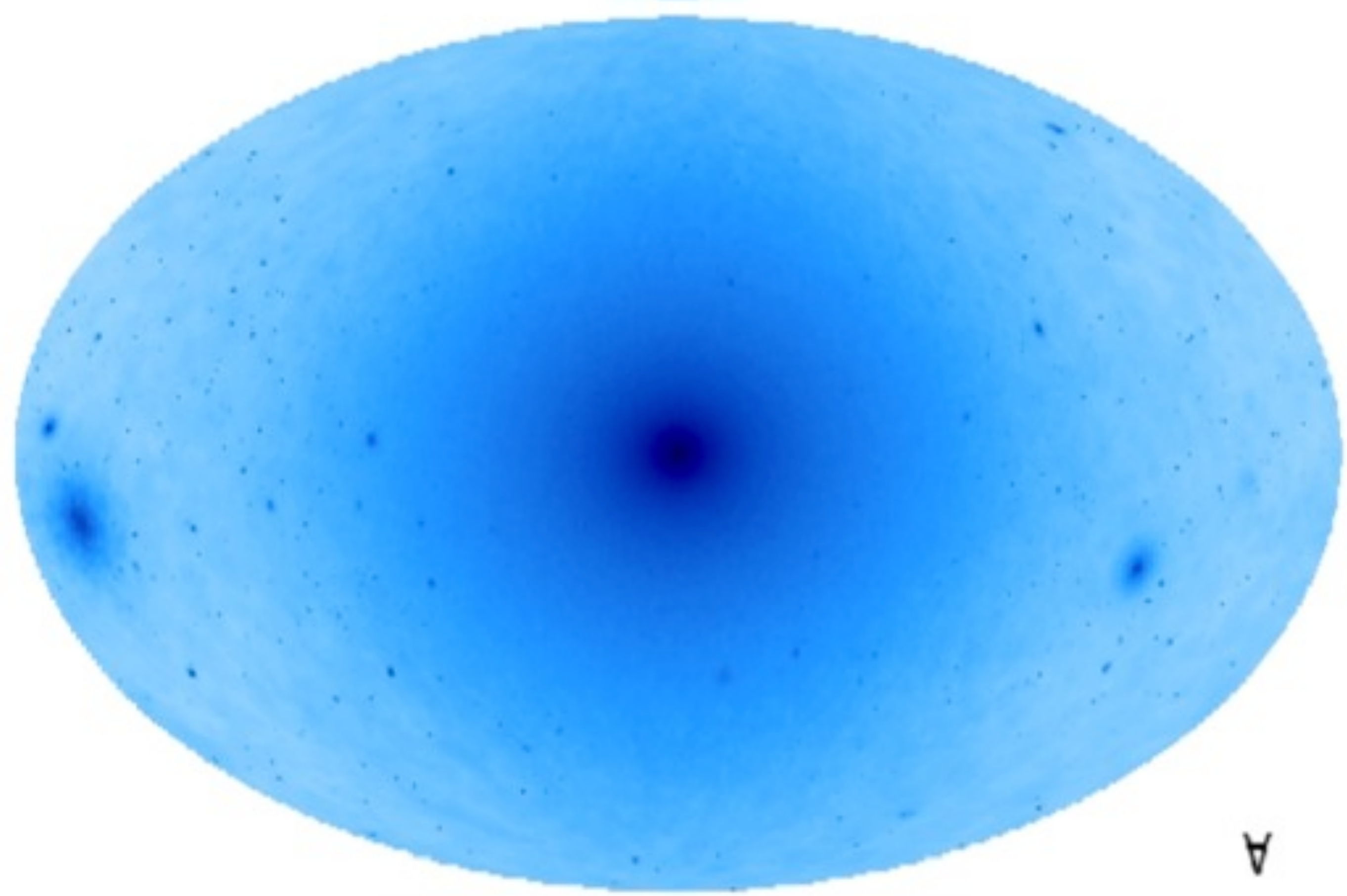
Backup Slides

Gamma-rays from DM

$$E_\gamma \Phi_\gamma(\theta) \approx 10^{-10} \underbrace{\left(E_{\gamma,\mathrm{TeV}} \frac{dN}{dE_{\gamma,\mathrm{TeV}}}\right) \left(\frac{\langle \sigma v \rangle}{10^{-26}\mathrm{cm}^{-3}\mathrm{s}^{-1}}\right) \left(\frac{100\,\mathrm{GeV}}{M_\chi}\right)^2}_{\text{Particle Physics Input}} \underbrace{J(\theta)} \ \mathrm{erg\,cm^{-2}s^{-1}sr^{-1}}$$

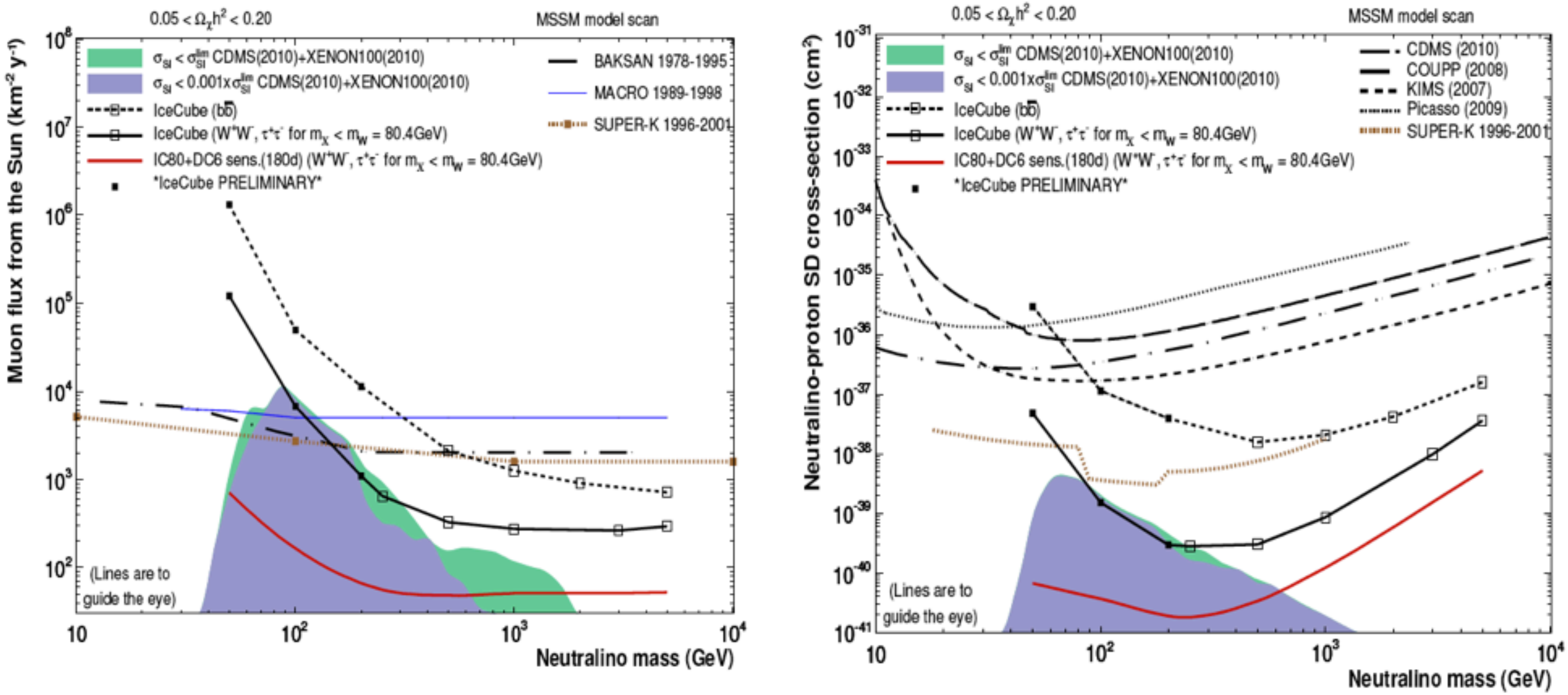
$$J(\theta) = \underbrace{\frac{1}{8.5\,\mathrm{kpc}} \left(\frac{1}{0.3\,\mathrm{GeV/cm^3}}\right)^2 \int_{\text{line of sight}} \rho^2(l)\,dl(\theta)}_{\text{Astrophysics/Cosmology Input}}$$





Line-of-sight integral of ρ^2 for a Milky-Way-like halo in the VL Lactea II ΛCDM N-body simulations (Kuhlen et al.)

DM Neutrinos from the Sun

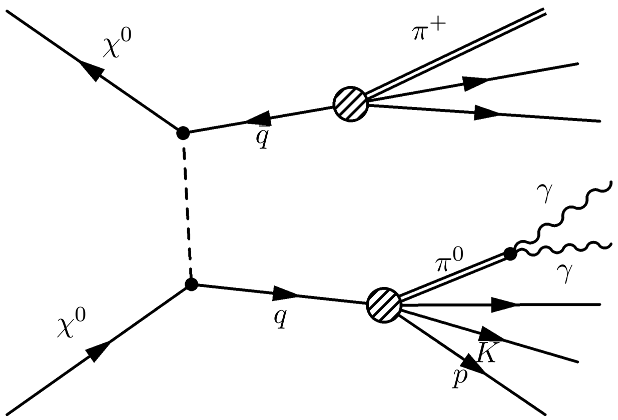


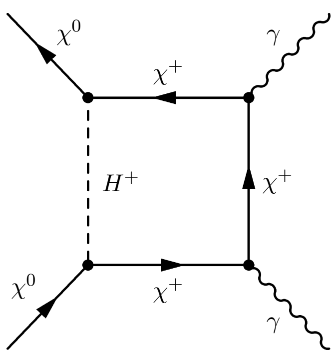
de los Heros for the IceCube Collaboration, Dec 2010, arXiv:1012.0184

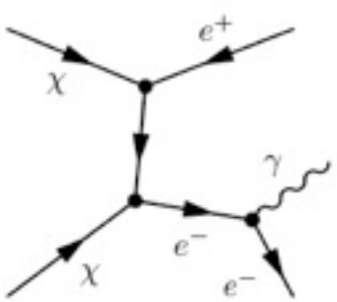
- Limits on the DM annilation flux and Spin-Dependent wimp-nucleon cross-section from IceCube compared with Direct detection limits

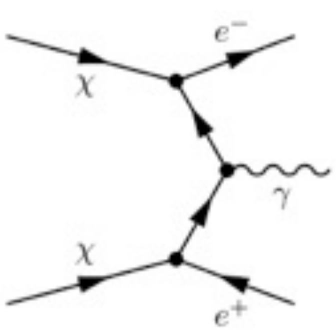
- In red, expected improvement in sensitivity with the addition of the six-string Deep Core detector

Annihilation Channels







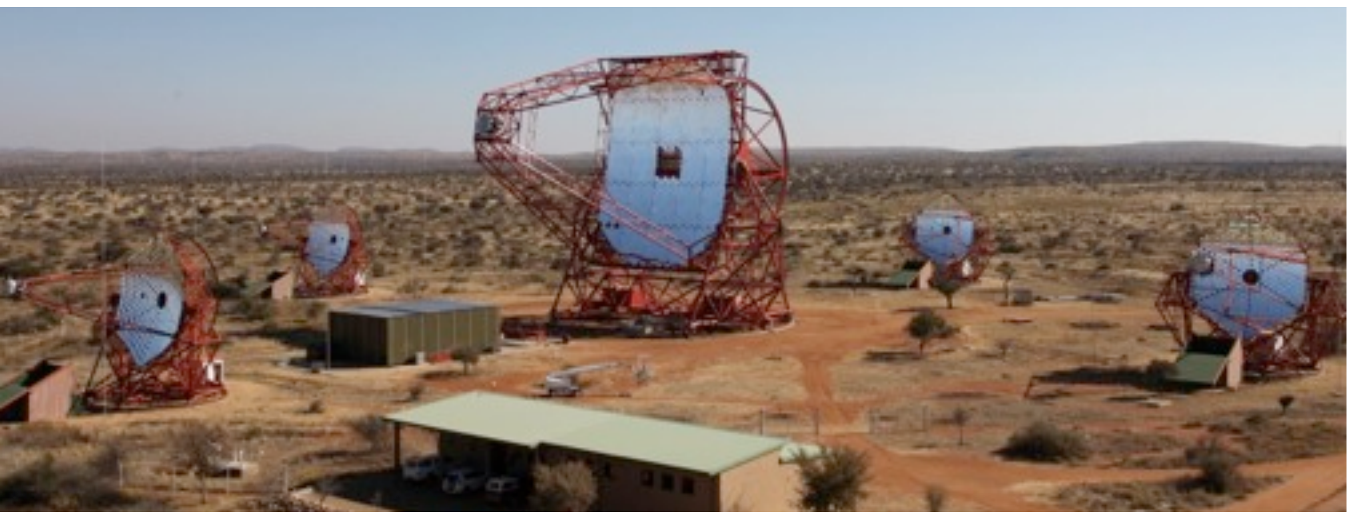


Annihilation Channel	Secondary Processes	Signals	Notes
$\chi\chi \to q\bar{q},\ gg$	$p, \bar{p}, \pi^{\pm}, \pi^0$	p, e, ν, γ	
$\chi\chi \to W^+W^-$	$W^{\pm} \to l^{\pm}\nu_l,\ W^{\pm} \to u\bar{d} \to \pi^{\pm},\ \pi^0$	p, e, ν, γ	
$\chi\chi \to Z^0Z^0$	$Z^0 \to l\bar{l},\ \nu\bar{\nu},\ q\bar{q} \to$ pions	p, e, γ, ν	
$\chi\chi \to \tau^{\pm}$	$\tau^{\pm} \to \nu_\tau e^{\pm}\nu_e,\ \tau \to \nu_\tau W^{\pm} \to p, \bar{p}$, pions	p, e, γ, ν	
$\chi\chi \to \mu^+\mu^-$		e, γ	Rapid energy loss of μs in sun before decay results in sub-threshold νs
$\chi\chi \to \gamma\gamma$		γ	Loop suppressed
$\chi\chi \to Z^0\gamma$	Z^0 decay	γ	Loop suppressed
$\chi\chi \to e^+e^-$		e, γ	Helicity suppressed
$\chi\chi \to \nu\bar{\nu}$		ν	Helicity suppressed (important for non-Majorana WIMPs?)
$\chi\chi \to \phi\bar{\phi}$	$\phi \to e^+e^-$	$e^{\pm}$	New scalar field with $m_\chi < m_q$ to explain large electron signal and avoid overproduction of p, γ

internal/final state bremms
inverse Compton γ's

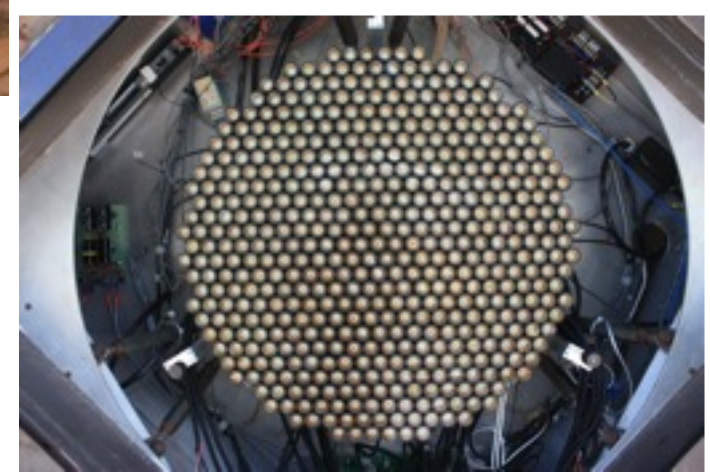
HESS-II and VERITAS Upgrade

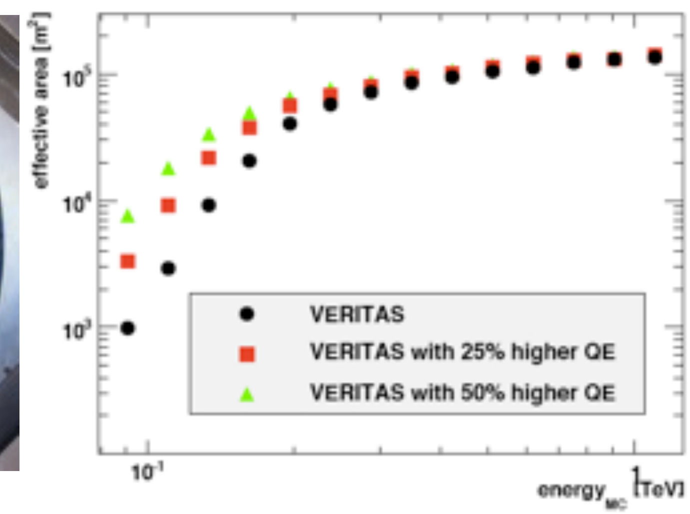
HESS II



- 28m HESS-II telescope added to 4 12m telescopes. Nearly operational, will provide very low threshold monoscopic-imaging, some reduction in threshold of HESS 12m telescope array for stereoscopic events.

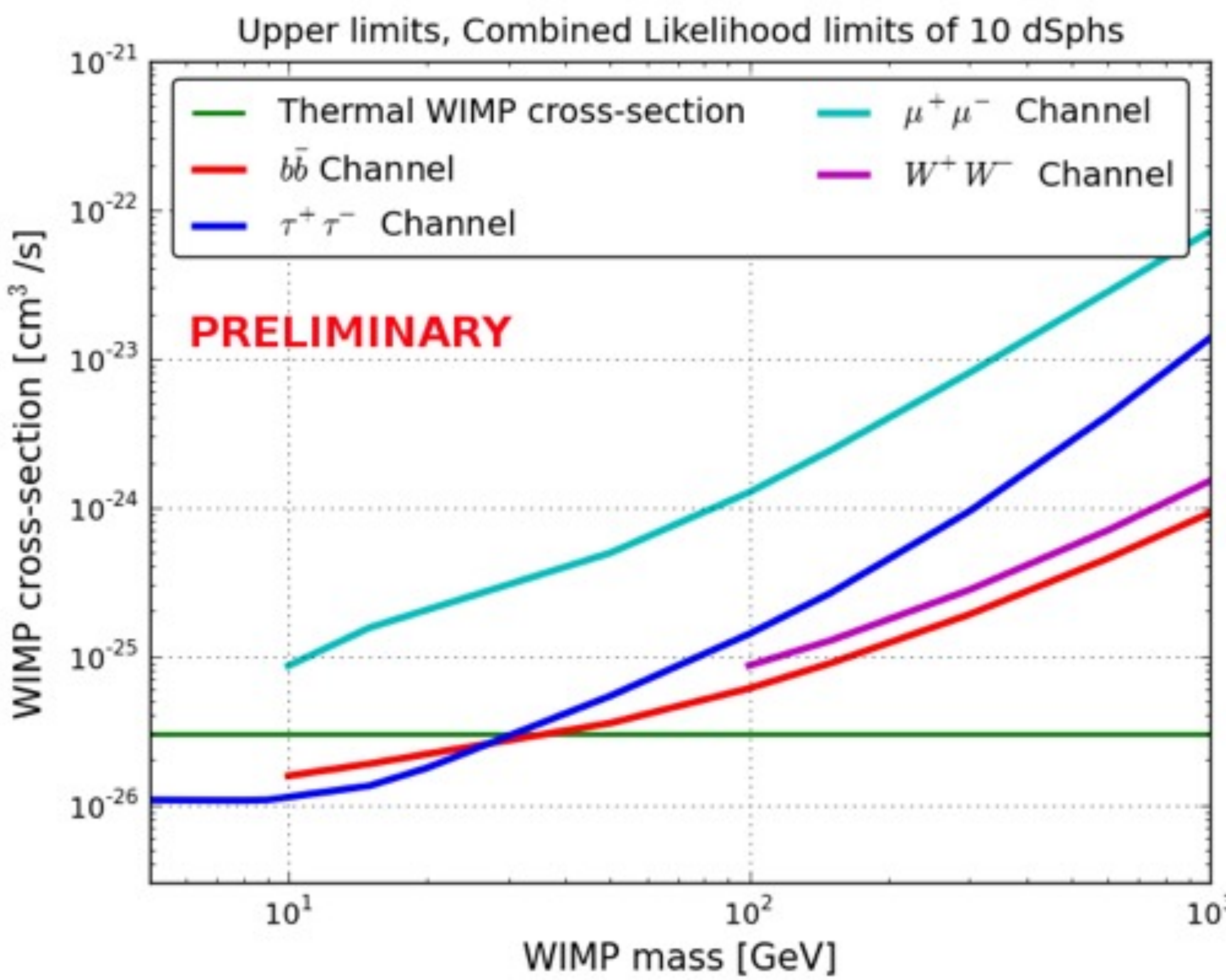
VERITAS′





- VERITAS upgrade (to be complete this summer) includes new trigger and replacing all PMTs wit new tubes with ~50% higher QE - like increasin mirror size from 12m to 14m diameter!

Dwarf Galaxy Limits

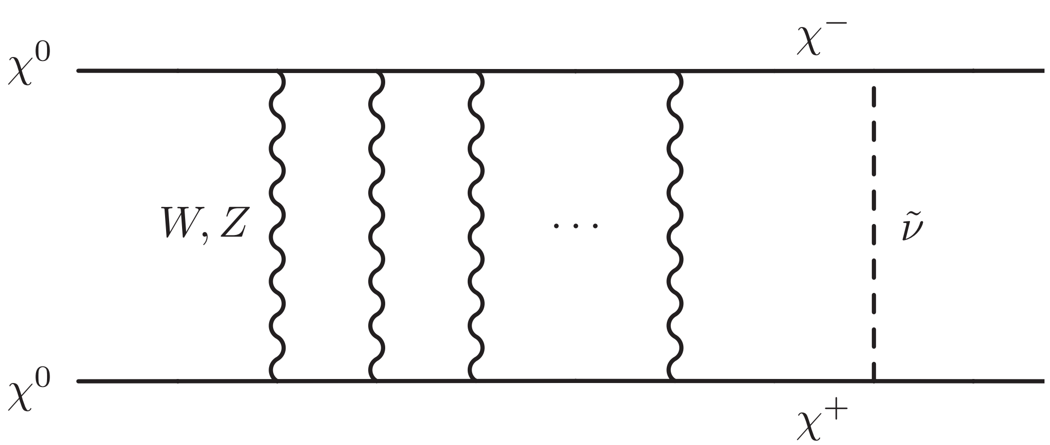


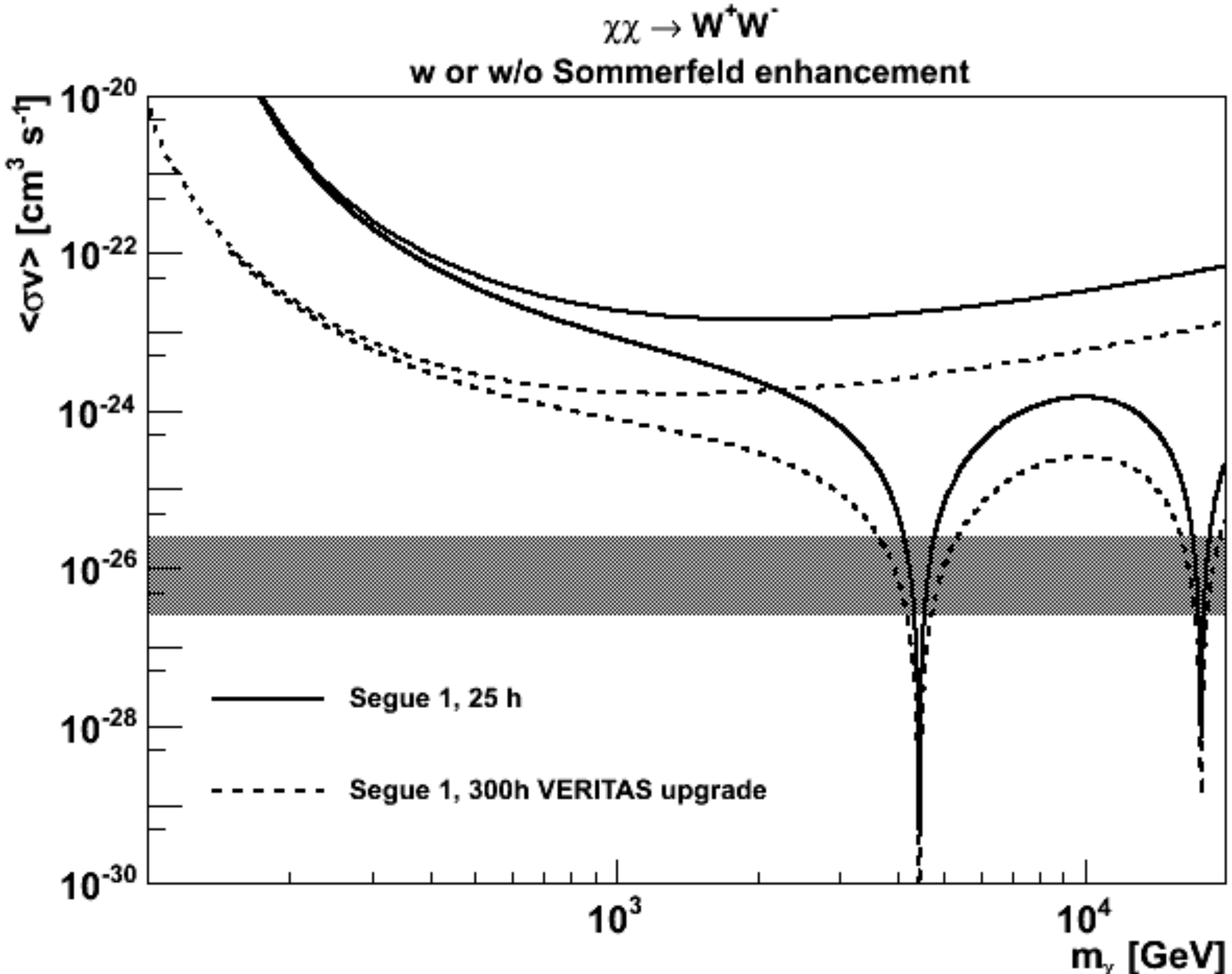
Liena Garde, M., Conrad, J., Cohen-Tanugi, J. for Fermi-LAT Collaboration, Fermi Symposium, May 2011

Stacking dwarf results brings Fermi upper limits in range of the natural cross section for annihilation at energies < about 30 GeV. *Possibly one of the best constraints on WIMP dark matter provided by any technique.*

W/Z Sommerfeld Enhancement

At sufficiently high neutralino masses, the W and Z can act as carriers of a long-range (Yukawa-like) force, resulting in a velocity dependent enhancement in cross section (1/v or even $1/v^2$ enhancement near resonance)



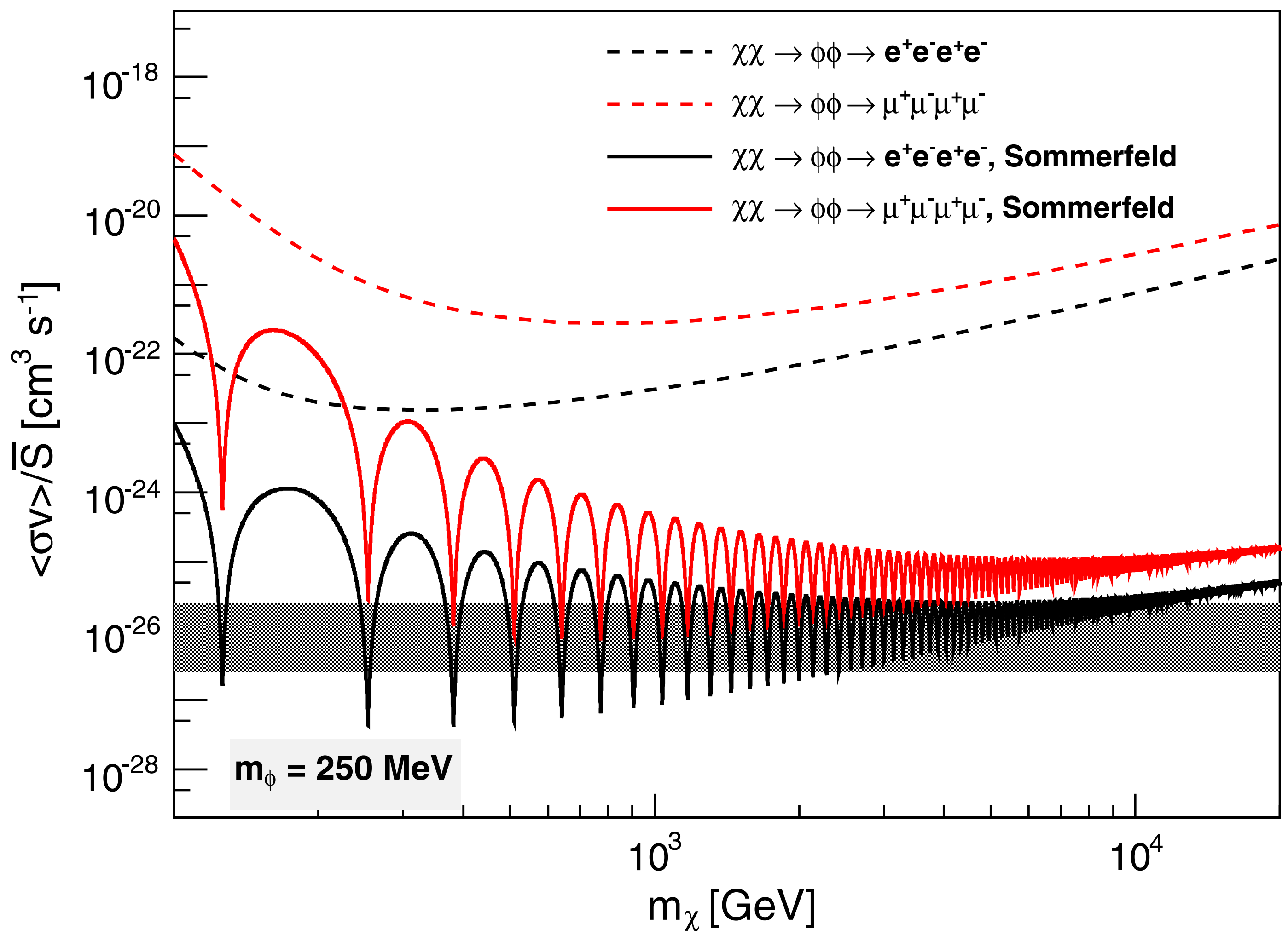


(Matthieu Vivier et al. for the VERITAS Collaboration, 2011, ICRC proceedings)

- At high mass, expect Sommerfeld enhancement from W, Z exchange for standard neutralinos can give large enhancement in present annihilation cross section (lower relative velocity) compared with decoupling cross section (higher velocity).

VERITAS Segue I Results

PHYSICAL REVIEW D **85,** 062001 (2012)



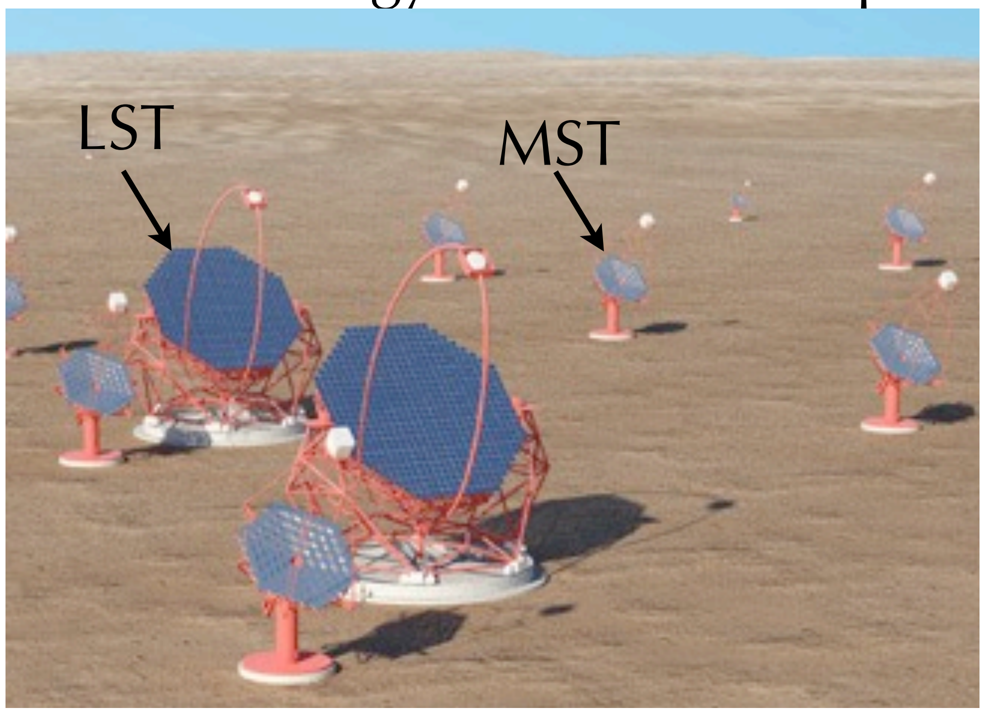
(Talk by Andy Smith, Friday Indirect Parallel)

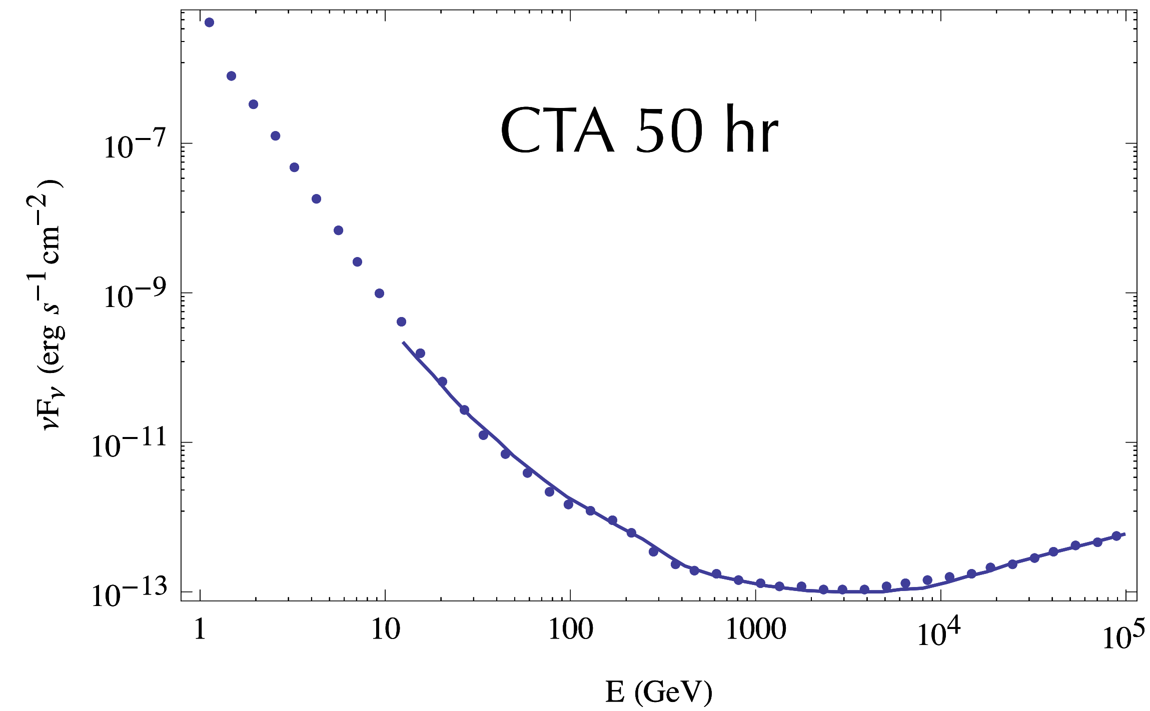
- PAMELA-inspired models predict large neutralino masses, and invoke new scalar fields to explain high branching ratio to leptons, and large (Sommerfeld-enhanced) cross section

- *VERITAS Segue I limits provide tight constraints on leptophillic models*

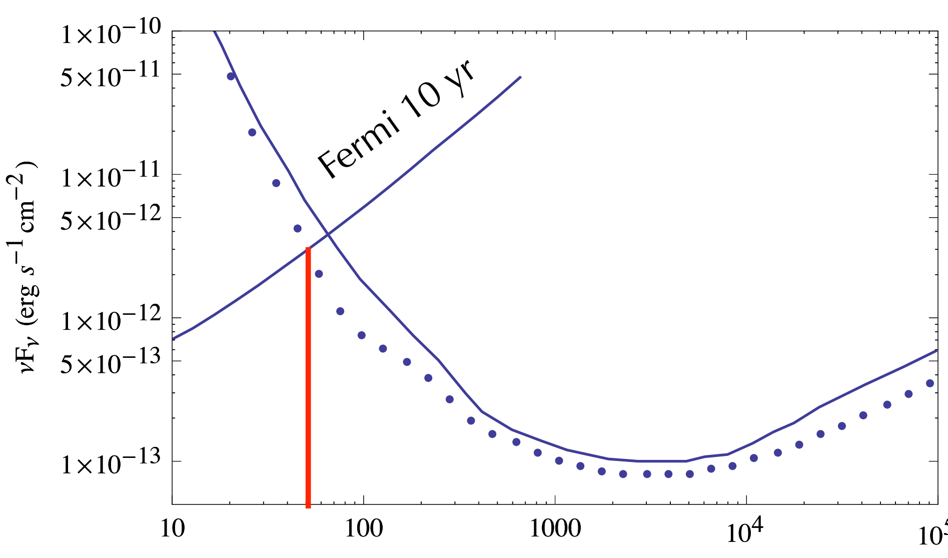
Optimizing Array Design

Energy threshold is important, but do we build more LSTs or MSTs?

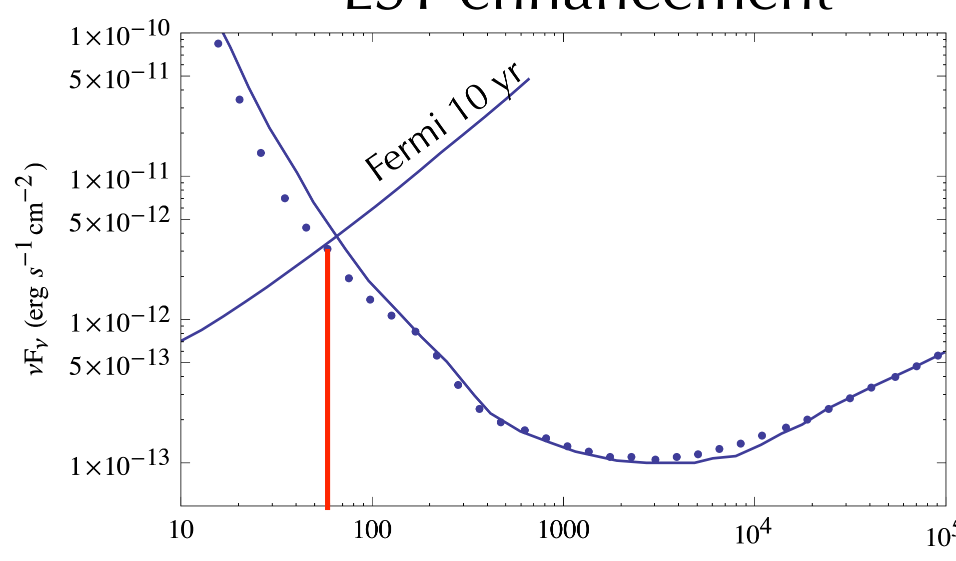




MST Enhancement



LST enhancement



Fit analytical model to CTA sensitivity and scaled MST and LST to ~equal enhancements.

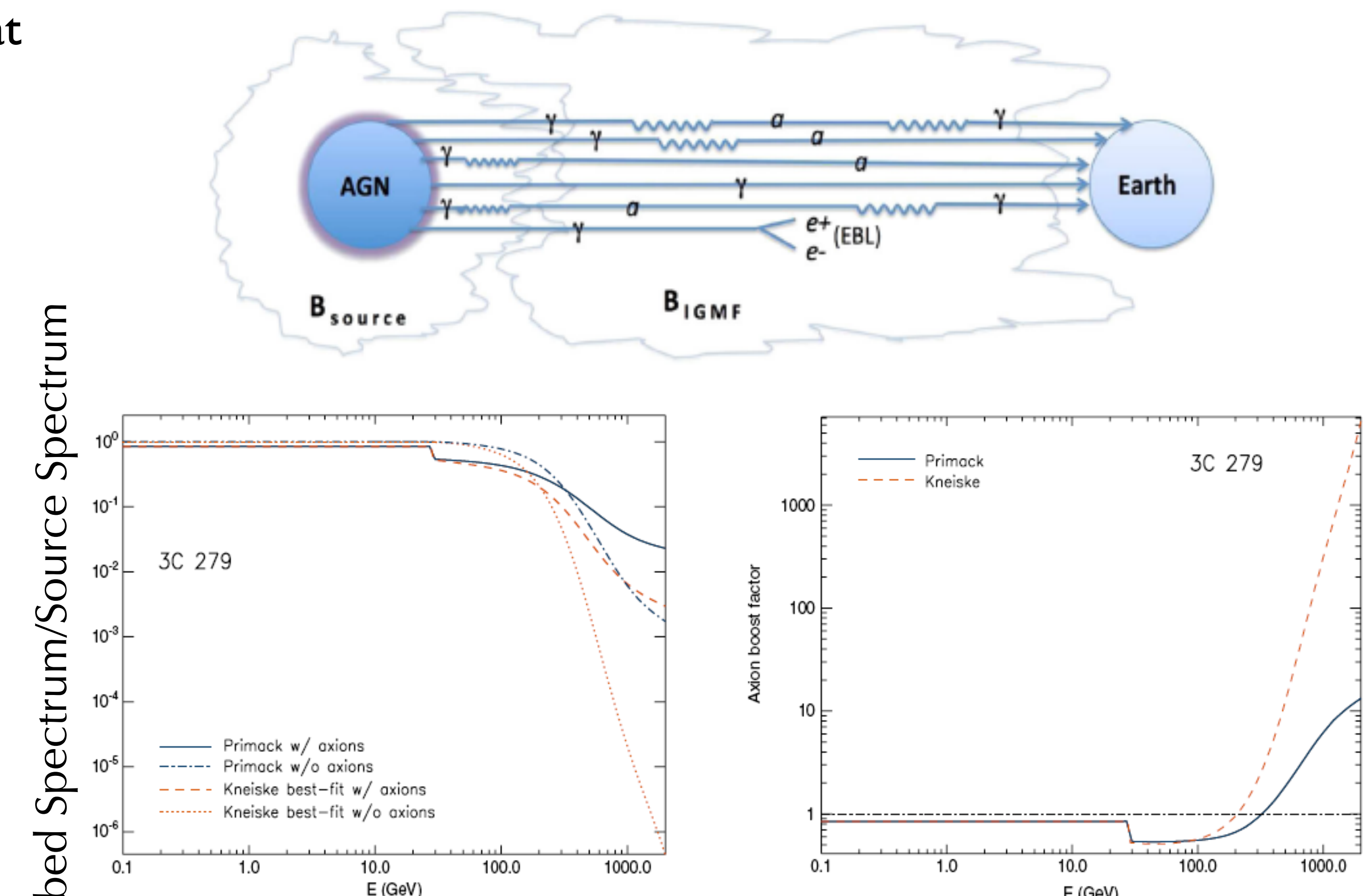
** When taking Fermi into consideration, additional MSTs seem like the correct approach*

Photon-Axion Mixing

Hooper and Serpico, PRL 99, 231102 (2007)

Sanchez-Conde, Paneque, Bloom, Prada & Dominguez, Phys. Rev. D 79 (2009) 123511

- Photon-ALP mixing can happen at the source, or during photon propagation in the presence of intergalactic magnetic field.
- One signature of this effect will be a relatively sharp drop of ~30% in the spectrum between 1 and 100 GeV.
- Another effect is that mixing could make some photons travel to Earth as axions and then convert back to photons. Axions would not be attenuated by EBL. Therefore, one could expect to see less EBL absorption than expected at E~1TeV for distant sources. The boost effect could be of factor ~100 in the most optimistic scenarios.



The flux increase due to axions propagating through EBL could be tested with VERITAS by observing distant sources. The effect could be disentangled from our ignorance of EBL density by seeing the effect in multiple sources at different z.